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Citation for published version (APA):

Rose, N. S., Aicardi, C., & Reinsborough, M. T. (2015). Foresight report on future neuroscience.

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Foresight report on Future Neuroscience

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1. Executive Summary

The **Human Brain Project (HBP)** is one of the Future and Emerging Technology Flagship initiatives funded by the European Commission. It is a ten-year initiative in medicine, neuroscience and computing which brings together scientists and institutions from 20 nations across Europe, and has a strong element of international cooperation. The first 30 months of the project, the so-called ‘Ramp-Up’ phase, began in October 2013 and will run until March 2016; at this point, the HBP will move into its Operational Phase.

Following the presentation of our first Foresight Report on Future Medicine¹, where the issues of data federation and disease signature were explored in relation to the work of the Medical Informatics Platform (MIP), the HBP Foresight Lab at King’s College London (Work Package 12.1) has been focusing on the topic of Future Neuroscience.

This work was originally planned to explore the conceptual and epistemological questions raised by different approaches to model building in neuroscience, exploring their characteristics (top-down, bottom-up) and the different relations between data and models, experimenters and modellers.

After a technical review run by the European Commission, some relevant initiatives organised by the HBP Consortium, and a workshop organised at the Fondation Brocher (Hermance, Switzerland), it was decided to focus on the study of the possibilities, issues and practicalities in collaborative neuroscience, paying heed to the collaboration between diverse brain modelling communities and approaches.

Specifically, the two themes of this report are: a) building an infrastructure for Future Neuroscience, b) building a community for Future Neuroscience.

We studied these issues in the frame of a short timescale, because we believe that they may have implications for strategic decisions that have to be made concerning the management of that aspect of the HBP’s work.

Based on our research and our discussions, we make a series of recommendations.

Building an infrastructure for Future Neuroscience

In this section, we considered the challenges faced by the teams designing and building the Neuroinformatics and Simulation platforms. We found that the main challenges they face broadly align with two essential components of the HBP strategic objective for Future Neuroscience: scaling small data, and bridging scales.

A research and innovation technological infrastructure reflects and embodies a certain social organisation involving power relations. Therefore, technological fixes cannot always replace social solutions. At the individual level, incentives and success metrics for new academic profiles (curators; ‘bridge scientists’) must be found for rewarding the sharing of data. At the interpersonal level, trust and mutual understanding should be encouraged.

A flexible strategy should be developed for an improved communication flow between the various individuals and entities.

New approaches need to be adopted to link the work of the Medical Informatics Platform into existing networks, organisations and patient groups concerned with psychiatric and neurological disorders.

There is a need for dedicated curators of data and metadata within the Neuroinformatics Platform, who have the appropriate interdisciplinary background to address the challenge of scaling up small data and that of bridging scales, and also to identify possible complementarities and act as broker between research groups.



The integrative design of the Human Brain Project infrastructure must take care not to over-privilege certain characteristics of the brain to the detriment of key aspects like plasticity and neuromodulation.

Building a community for Future Neuroscience

In this section, we focused on the factors that may determine the success or failure of potential neuroscience transitions, that is to say the social factors involved in building a neuroscience community which can take advantage of what the HBP has to offer.

Building an infrastructure to support Future Neuroscience must include and reach out to the broader community that can, and wants to, make use of this infrastructure. It is therefore necessary to consider how design decisions can affect the social organisation of the future research community, consulting with potential users in the design process.

Since interdisciplinary collaboration is an intrinsic part of this process, it is important that sufficient resources and time are allocated for establishing interdisciplinary work. Moreover, support should be developed for new academic profiles (curators; ‘bridge scientists’) and in some cases, for new methods for assessing unusual interdisciplinary research output.

A participatory research community needs to encourage individual researchers to understand their role within the community; this is why a programme of researcher awareness should aim to support researchers’ knowledge of their own role and impact within the research community, and to include researchers’ interactions with other potential user communities, especially clinical neuroscience and patient communities.



2. Introduction

2.1 What is the Human Brain Project

The Human Brain Project is structured around a number of key objectives:²

- 1) Simulate the Brain: Develop ICT tools to generate high-fidelity digital reconstructions and simulations of the mouse brain, and ultimately the human brain.
- 2) Develop Brain-Inspired Computing and Robotics: Develop ICT tools supporting the re-implementation of bottom-up and top-down models of the brain in neuromorphic computing and neurorobotic systems.
- 3) Develop Interactive Supercomputing: Develop hardware architectures and software systems for visually interactive, multi-scale supercomputing moving towards the exascale.
- 4) Map Brain Diseases: Develop ICT tools to federate and cluster anonymised patient data.
- 5) Perform Targeted Mapping of the Mouse Brain and the Human Brain: Generate targeted data sets that can act as anchor points for future data generation and for high-fidelity reconstructions of the brain.
- 6) Develop a Multi-Scale Theory for the Brain: Develop a multi-scale theory of the brain that merges theory-based, top-down and data-driven, and bottom-up approaches.
- 7) Develop and Operate six ICT Platforms, Making HBP Tools, Methods and Data Available to the Scientific Community: Develop and operate six specialised Platforms dedicated to Neuroinformatics, Brain Simulation, High Performance Computing, Medical Informatics, Neuromorphic Computing, Neurorobotics, and a Collaboratory providing a single point of access to the Platforms.
- 8) Catalyse Revolutionary New Research: Leverage investment in Platform development to catalyse a phase shift in neuroscience, computing, and medical research.
- 9) Drive Collaboration with other Research Initiatives: Establish synergistic collaborations with national, European, international and transnational initiatives contributing to the Strategic Flagship Objectives.
- 10) Drive Translation of HBP Research Results into Technologies, Products and Services: Promote engagement with industry to translate HBP research results into technologies, products and services benefitting European citizens and European industry.
- 11) Education and Knowledge Management: Implement a programme of transdisciplinary education to train young scientists to exploit the convergence between ICT and neuroscience, and to create new capabilities for European academia and industry.
- 12) Pursue a Policy of Responsible Research and Innovation: Implement a strategy of Responsible Research and Innovation, monitoring science and technological results as they emerge, analysing their social and philosophical implications, and raising awareness of these issues among researchers and citizens, involving them in a far-reaching conversation about future directions of research.

2.2 Responsible Research and Innovation and the Foresight Lab

From its inception, the HBP has integrated the principles of responsible research and innovation (RRI) into its design, and established a Society and Ethics Subproject (to be renamed Responsible Research and Innovation) to manage, oversee and ensure that the principles of RRI are embedded in the research.³ This Subproject will monitor science and



technological results as they emerge, analyse their social and philosophical implications, and work to involve researchers, decision-makers, and the general public in a far-reaching conversation about future directions of research. The Foresight Lab at King's College London, which has produced the present research, is part of this Subproject.

The overall strategy adopted for RRI involves four interlinked components: anticipation (of future implications, based on research); reflection (activities to enhance ethical and social awareness and reflection among HBP researchers; engagement (engaging, disseminating and debating HBP research with stakeholders and the general public); and action (ensuring the results of these activities help shape the direction of the HBP itself in ethically robust ways that serve the public interest).

A central aim is to identify potential ethical and social concerns at an early stage and to address them in an open and transparent manner, providing HBP scientists with opportunities to gauge public reaction to their work, and to hone their research objectives and processes accordingly. The programme for RRI draws on the methods developed during empirical investigations of emerging technologies in genomics, neuroscience, synthetic biology, nanotechnology and information and communication technologies.

HBP research operates in a climate of high expectations of social and economic benefits. However, the impact of basic research results on society often depends not as much on the research itself as on developments in apparently unconnected areas of science and technology, or on social, political and legal factors external to science (Guston, 2014; Stirling, 2015; Nuffield Council on Bioethics, 2012). Foresight exercises play a central role in responsible innovation as they enable 'anticipatory' action to shape the pathways of development in desired ways, and to assess and manage risks in a timely manner (Guston, 2011; Calof and Smith, 2012; Cuhls *et al.*, 2012; Owen *et al.*, 2012).

Current approaches to forecasting development pathways use two strategies, both of which are used in the Foresight Lab of the HBP. The first studies the views, attitudes and strategies of key stakeholders with methods from the empirical social sciences. The second uses systematic foresight techniques such as modelling, horizon scanning and scenario planning. The goals of these exercises are, on the one hand, to identify new developments and assess their potential impact over the short, medium and longer term; on the other to assess key ethical concerns such as privacy, autonomy, transparency, the appropriate balance of risks and benefits, responsibility and accountability, equity and justice. One aim of these foresight exercises is to feed back into the work of the HBP itself, and to encourage reflection among researchers and their leaders. This kind of general reflexivity is not currently the norm and may well meet resistance, but it is nevertheless a key component of Responsible Research and Innovation (Owen *et al.*, 2012; Stilgoe *et al.*, 2013).

The HBP Foresight Lab is testing new approaches for integrating responsible research and innovation with emerging biotechnologies. It undertakes a multi-institutional process of capacity building, both within the HBP and with relevant constituencies outside. It considers questions of institutions, research and innovation systems, business and investment strategies and their implications, public values (including those of consumers and patients), and challenges for governance. The Foresight Lab uses an iterative process in which the views and priorities of different communities interact with one another in an expanding dialogue, and feed back into the direction, management, and priorities of HBP researchers.

2.3 Foresight Lab Reports and Methods

This is the second of the three reports that the Foresight Lab will produce in the Ramp-Up Phase. The HBP Foresight Lab released a first Foresight report on Future Medicine in March



2015, which focused on the work of the Medical Informatics Platform.⁴ We will publish a 3rd Foresight Report on Future Computing and Robotics in March 2016, which will concentrate on the Neurorobotics, Neuromorphic Computing and High Performance Computing platforms. The target of the present foresight report is future neuroscience, and we have focused on the Neuroinformatics and the Simulation platforms accordingly.

Our aim in this report is to explore some of the key social and ethical issues that are emerging, or can be predicted to emerge in relation to the HBP's strategic objectives concerning future neuroscience. We have chosen to focus on a relatively short timescale, and consider issues that could emerge over the life of the project and hence that have implications for strategic decisions that have to be made concerning the management of that part of the HBP's work.

In the activities leading to our first Foresight Report on Future Medicine, the Foresight Lab used a method built on scenario construction. We developed narrative and fictional short scenarios (vignettes) and sets of questions to explore key future medicine issues arising from data federation, data mining, the search for brain signatures, and the development of personalised medicine. The method was appropriate to the timing of the task, which took place during the first year of the Ramp-Up Phase, while research approaches and directions were not yet settled.

In contrast, most of the activities leading to the present Foresight Report were undertaken following the conclusions of the first technical and ethical review of the project by the European Commission, and of a mediation process involving representatives of the HBP and of external stakeholders. We thus took as our starting point the scenario emerging from the main recommendations and requirements held in these conclusions. The detailed development of this scenario occurred in parallel and at times in interaction with our activities, and forms the backbone of the Framework Partnership Agreement, defining the strategic roadmap of the Human Brain Project for the Operational Phase of the project.

In preparing this report, we have used a number of methods. In addition to reviews of all the relevant literature, both in the scholarly journals and in the internal and working documents of the HBP, we have conducted a number of specific activities.

In January 2015, we took part in the webinars organised by the Danish Board of Technology Foundation (DBT), a partner in SP12: *Dual use and neuroscience. An online debate on current developments*. The webinars tackled the issues of dual use issues in biotechnology and infectious disease, prevention of misuse, the ethics of Artificial Intelligence and autonomous weapons, and an introduction to dual use and neuroscience. More information on the webinars can be found online⁵.

In May 2015, we participated in the expert seminar *Theory and data for advancing Future Neuroscience and the Human Brain Project* (HBP)⁶, organised by the European Institute for Theoretical Neuroscience (EITN) together with the DBT. The seminar anticipated some of the themes that were discussed at the workshop we organised at the Fondation Brocher the following month, specifically the building of a community for use and co-design of the ICT platforms, and the dialogue within the international neuroscientific community.

In June 2015, we organised a workshop held at the Fondation Brocher, in Hermance, Switzerland⁷: *Building a Neuroscience Community: community modelling and data repositories*. A full report of the workshop is available online⁸.

The workshop's overall aim was community building, taking as its main focus the practices and mechanisms for collaboration and integration, with the view to developing a concrete 'action plan' and 'roadmap' for tackling the various social, technological and scientific challenges that this poses. Specifically, we explored and debated the practices and developments that would support the growth of collaborative neuroscience with a focus on computer modelling communities. The intention was to give these communities an



opportunity to shape the future work of HBP Platform developers and to build collaborations in directions beneficial to neuroscience.

Besides organising and participating in a number of events and initiatives, we have been holding conversations and formal/informal discussions with key members of the HBP and the non-HBP neuroscience community.

2.4 Background to this report

The 1st periodic review of the Human Brain Project took place in Brussels, 26–28 January 2015. Based on the conclusions of the reviewers, delivered early March 2015, the European Commission supported the continuation of the HBP, but recommended some significant modifications in governance, scientific goals and organisation.

The corrective actions to be implemented fell under three main headings:

- Closer integration of the data and theory Subprojects with the development of the ICT Platforms, and re-integration of systems and cognitive neuroscience
- Achieving the goal of an integrated ICT infrastructure for the scientific community
- Effective organisation and management of the project.

In parallel, a process of mediation unfolded, formally initiated by the HBP Board of Directors in response to criticism of the project. This criticism came to public attention in July 2014 in an open letter to the European Commission signed by several hundred scientists, demanding modifications to both the management structure and the scientific focus of the project. The recommendations formulated by the Mediation Process Working Groups, also delivered in early March 2015, and largely echoed the corrective actions required by the Commission.

As a response, a number of decisions were made by the HBP Board of Directors, with immediate effect. In particular, three working groups were constituted, dedicated to the three areas for corrective actions. The Governance Working Group devoted itself to the revision of the governance structure. The Data and Theory Working Group concentrated on building a strategy for aligning the data-producing and theory activities, for integrating them with the HBP infrastructure design, and for bringing back systems and cognitive neuroscience into the project so as to develop transversal cooperation and synergy. Finally, the User Recruitment and Infrastructure Strategy Working Group focused on devising a plan for translating the six projected platforms into a solid integrated ICT infrastructure, and on drafting an accompanying roadmap for user recruitment.

The work of the three working groups has been closely associated to the development of the Framework Partnership Agreement (FPA), negotiated between the Human Brain Project and the European Commission. This is the agreement for the Operational Phase of the project, following the Ramp-Up Phase, which ends at the end of March 2016. The FPA sets out the contractual conditions under which the HBP will operate in the European Commission Horizon 2020 research programme, and for the remainder of the project. A number of actions included in the FPA area already being implemented proactively, without awaiting the end of the Ramp-Up Phase.⁹

This is the context in which the HBP Foresight Lab has prepared the present report on Future Neuroscience. The iterative process of the development of the scenario forming the backbone of the FPA, occurred in parallel and at times in interaction with our activities. Based on these developments we have chosen to focus this report on two key issues:

- Building an infrastructure for Future Neuroscience
- Building a community for Future Neuroscience



3. Building an Infrastructure for Future Neuroscience

3.1 The Objectives for Infrastructure Building

The strategic objective of the HBP for Future Neuroscience has remained constant since its inception: “achieve a unified, multi-level understanding of the human brain that integrates data and knowledge about the healthy and diseased brain across all levels of biological organisation, from genes to behaviour; establish *in silico* experimentation as a foundational methodology for understanding the brain.” In this section, we consider the challenges faced by the teams designing and building the Neuroinformatics and Simulation platforms, as they try and reconcile this strategic objective with the constraints that arise from the aim, on the one hand, to turn the HBP into an integrated research infrastructure and to build a user community for neuroscience, while, on the other hand, requiring that the four re-organised data and theory Subprojects should be closely involved in the co-design of the Platforms as their first users.

We have found that the main challenges they face broadly align with two essential components of the HBP strategic objective for Future Neuroscience, which stem from the project’s original aspiration to remedy the fragmentation of brain research and of the data it produces: scaling small data, and bridging scales.

3.2 Emerging Challenges

3.2.1 Scaling small data

In neuroscience, datasets are especially diverse and complex—much more than genomics sequence data for instance, despite repeated analogies being made between the Human Brain Project and the Human Genome Project:

“The relevant variables may include morphology, functional connectivity, neurophysiology, chemistry, molecular Biology, genomics, brain imaging and behaviour. These variables may change over time scales ranging from milliseconds to years, and may be subject to diverse experimental manipulations. Many other factors may also contribute to the context of an experiment and be essential for its interpretation.” (Koslow, 2000)

Although in the present phase of the project, only a small fraction of the global neuroscience community participates in the HBP and the project focuses on just two organisms (mouse and human), it is nonetheless representative of this diversity and complexity. At our workshop hosted by the Fondation Brocher, a collaborator of the HBP Neuroinformatics team summarised its present situation by saying: “we have one of everything but not much of anything.” Faced with this paucity of data, the HBP Neuroinformatics team argues that “a three-pronged strategy is needed. First, integrate existing data from different labs. Second, predict missing data that have not (yet) been measured. Third, increase the amount of available experimental data through new molecular neurobiology techniques and industrial neuroscience approaches” (Tiesinga *et al*, 2015).

This is a characteristic case of transforming ‘small data’ by scaling them into data infrastructures, and preserving them for future and repeated use.¹⁰ For all such projects, the general rationale behind the thrust for integration is that it could yield much insight and value (Kitchin, 2014). In the case of the HBP, it is hoped that besides maximising the value for research funding money, such transformation will help map the human brain across all its levels and functions, and ultimately understand it.



Sharing data

Regarding the first prong of the strategy outlined above, not only must the HBP rely on dozens of different labs with different research traditions and practices to provide it with strategic data, but it also aims to mine published neuroscientific research for additional data. Further, the Neuroinformatics Platform, currently co-designed with the data-producing and theory Subprojects (SPs 1–4), works towards opening up to the outside world by the end of the ramp-up phase in April 2016, for the use of both data consumers and data producers - who are actually often the same people, as was pointed out during the workshop at the Fondation Brocher.

Beyond the labs already participating in the project, the HBP needs to convince neuroscientists in the wider community to share their datasets through the Neuroinformatics platform, when, even within the project, some are reluctant to do so. The reluctance stems from a number of reasons, of which the most common are:

- “ - No one else can understand the complexity of my data.
- If someone else analyses my data, they may come up with a different answer, disproving my perspective.
- Someone else may find something new in my data that I did not see.
- It is my data that I worked very hard to collect, and no one else has the right to it.
- I have not finished analysing my data, and I will make it available once my analysis is complete.
- I cannot trust or understand the data produced in another laboratory.” (Koslow, 2000)

One issue on which we all agreed in our discussions is the cost required—in time and resources—to prepare datasets for sharing. There have to be incentives to compensate for such investment. The incentives that are most often envisaged involve recognition in a form that will fit academic reward structures—the first of these being cited as co-author in publications. Others have suggested the need to start thinking outside of academic reward structures, to consider incentives that would compensate in kind for the time and resources consumed. For instance, often, the individual labs simply do not have the resources for properly curating their data—even for their own potential re-use—and thus data curation is a service from which they could benefit, especially if it comes assorted with time-saving tools (like for instance, automated generation of experimental protocols, or of publication-ready code). The HBP has to consider whether it is something that the Neuroinformatics platform will offer beyond the strategic data-producing labs which are part of the HBP—to whom and under which conditions—or if it will simply harvest the metadata characterising datasets and leave the curation work to external repositories.

From ‘cottage industry’ to ‘big science’

Data integration, in the case of neuroscience, also aims to transform neuroscience from a ‘cottage industry’ into ‘big science’ (Koslow, 2000). This has strong implications for experimentalists producing the data. It raises the risk of changing the nature of the data producers’ labour by displacing data production from being predominantly a skilled craft towards becoming an increasingly industrial process—in short, privileging the ‘data factory’ model over the small lab ‘artist-artisan’ model. This is in fact the third prong in the strategy advocated by the HBP Neuroinformatics team. And it is the strategy that is for instance implemented, in the Mouse Data Subproject (SP1), through partnering with Wenzhou Medical College in China.

A common complaint of small labs’ experimentalists is that large-scale big-science initiatives tend to ignore them and be dismissive of the skills and experience that go into the work they produce. For instance, according to a member of the Neuroinformatics



team, when the Allen Brain Institute—whose work is presented as a key example of the ‘three-pronged strategy’ (Tiesinga *et al*, 2015)—started to produce their brain maps, many small labs that were doing this type of work were worried that they would disappear. Most actually survived, but they did so by changing the focus of their work, to concentrate on tasks where their specialist skills could bring added value. They focused on undertaking pioneering experiments of the kind that usually cannot be done in ‘data factory’ labs, which tend to do solid but not innovative work. This suggests that a new relation is required between the different participants, in which the big players must also realise their own limitations. For instance, they may be physicists or chemists and produce data of unparalleled quality thanks to the equipment they can afford, but they often do not have the scientific acumen of the neuroanatomists, that is to say, the ‘tacit knowledge’ which is born from experience (Collins, 2010).

Our conclusion from these discussions is that it is necessary for the HBP to explicitly address this issue, if it is to show to experimentalists in the wider community that it is supporting *all* neuroscience research—it is not trying to put them out of business, but to make their work easier by providing them with services and helping them build better tools. To build collaborative relations among the whole community, the HBP must be clear that alongside the speed and systematicity that flow from industrial processes, there is still going to be a place for the innovation that requires the skills, training and experience of individual ‘artists’. Thus the HBP should also have a role to play in ameliorating some of the antagonisms, by bringing together the ‘data artisans’ and the ‘data industrials’ to identify possible complementarities.

There is a further ethical issue raised by the industrial neuroscience approach. Industrial labs follow strictly specified experimental protocols and delivery formats to produce so called ‘raw’ data, which are in effect un-interpreted and decontextualised data unmoored from their conditions of production. This has a number of potential consequences that must be taken into account. The politics of raw data is a topic that has been attracting increasing attention in recent years (see for instance, Gitelman (ed.), 2013). In the present case, there are two points of particular relevance:

- Displacing the specification of experimental protocols from the data producer to the data aggregator, who controls the appropriate formats of delivery, effectively transferring skills from the data producer to the data aggregator. This is also a transfer of power from the periphery to the centre, which can then prescribe many of the details and criteria of the work done in individual labs.
- Deskillling and decontextualizing the data production work opens the door to delocalisation that has been seen in other areas of manufacturing and industry. It runs the risk of transferring data production to countries where experimental work is cheaper and practiced under more precarious work conditions than in countries of the European Union.

Predicting data

The goal of predictive neuroinformatics—the second prong of the HBP Neuroinformatics team’s strategy—is to fill in missing data using methods that apply general principles to existing data. It builds from methods that have already been developed in other research fields that have faced comparable questions. Data prediction actually illustrates clearly the fact that data producers and consumers are often the same people. It is a data-driven process requiring the input of experimental datasets to which are applied various mathematical predictive modelling techniques (borrowing from statistics, matrix calculation, geometry, etc.)— and it is guided by the assumption that the more data, the better the prediction. An important issue for predictive neuroinformatics, besides the chronic lack of certain types of data and the very tentative nature of some theoretical hypotheses, is the lack of consensus on what counts as meaningful categories of



components in the brain. In particular, there is no consensus on how neurons should be categorised, on whether cortical columns (hypothesised cylindrical groups of approximately 100 000 neurons that make up the cerebral cortex of mammals) are a structure with a function or not, or even on how brain areas should be defined and delimited. This is a problem when predictive work relies heavily on such categorisation—for instance the estimated distribution of neuron types in a specific brain area (Horton and Adams, 2005; Kasthuri *et al.*, 2015; Reimann *et al.*, 2015; Tiesinga *et al.*, 2015; Underwood, 2015).

We will discuss further data consumption, modelling, and the question of meaningful categories of components in the brain, in following paragraphs.

More data sources

The three-pronged strategy will still not provide enough data for the purpose of the Human Brain Project. It requires the establishment of partnerships with data repositories and other data-integrating initiatives, at the international level, such as the one which already is already in place with the Allen Institute for Brain Science. Establishing partnerships with international institutions located outside the European Union comes with its lot of ethical issues, in two prominent areas where non-EU countries may not have the same legal and regulatory provisions in place: the ethical treatment of animals in animal experimentation (and by extension in humans), and data protection and privacy where human data are concerned.

If the HBP eventually wants to work with the three broad categories of actors that currently exist in the global neuroscience landscape—individual labs, data aggregators (e.g. the Open Connectome Project, NeuroMorpho)¹¹ and large institutional initiatives (e.g. BRAIN, the Allen Institute for Brain Science)¹²—its Neuroinformatics Platform must be flexible and prepared to play at times the role of ‘harvester’ (by meta-indexing these different levels of initiatives in their knowledge base), together with a more ambitious role as ‘validator’ to establish the quality of the data included, and also the difficult and often unrewarded role of ‘curator’, by building an archive of the best available data of a specific kind. It will also need to provide multiple ways to transform the data into the different formats in common use in the research community. The Neuroinformatics Platform is already curating the strategic datasets produced by the data Subprojects. Opening up its services as a repository more broadly requires some thinking, as it will mean making some decisions regarding who the service will be open to, and the means by which to achieve a sustainable infrastructure—a recognised weakness of data repositories in general. Besides, as was pointed out during the Hippocamp CA1 workshop, another important dimension of data repositories needs to be taken into account, which is that people will only deposit their datasets in a repository if they trust the team in charge.

Bringing the data together, and beyond

So far, we have discussed the issues related to data availability and access, although our brief overview of predictive data started blurring the boundaries. But a strategy for gaining access to sufficient data is only part of the data challenge for the Neuroinformatics platform. The other dimension of the data challenge is to integrate the diversity of datasets into a single infrastructure that can accommodate them together, and to develop a data model, with its associated metadata, which will ensure that researchers in diverse research and clinical fields will be able to use the resources offered, in ways that will meet their needs.

The objective of the Neuroinformatics Subproject (SP5) is for the Platform and brain atlases that it is developing to allow neuroscientists to collaboratively curate, analyse, share, and publish large-scale neuroscience data. SP5 is collaborating with the International Neuroinformatics Coordinating Facility (INCF), the Allen Brain Institute and



other international partners to develop a global data registry and knowledge base where not only data but also models and literature are registered and annotated with high-level metadata. This will allow for their use in multi-level brain atlases, of the kind that the Neuroinformatics Subproject is developing alongside the Neuroinformatics platform. The atlases and related tools will be an important resource for neuroscientists working on predictive and computational models. The brain atlases will be constructed by curating data, depositing them in the data registry and linking them to established atlas ontologies and coordinates for rodent and human brains. Central to the goal of curating the data analysis will be the development of tools for large-scale data analysis and data mining to be used in data-driven modelling. Giving access to large and diverse datasets, organised across the different levels of the brain and within standard spatial coordinate systems, will allow search and correlative analysis within and across data modalities. The necessary tools to register, anchor, align and integrate diverse multilevel data will be built and provided through the web portal, web services or downloadable applications. Packages for establishing data repositories with standard data services, including metadata indexing, search, and data-type specific services, will be provided.

Anchoring and aligning datasets in single ‘absolute’ coordinate system is a major concern of brain atlas, whether in mouse or human—the two organisms for which the Neuroinformatics Subproject is building atlases. A member of the Neuroinformatics team working on data integration explained that currently, all atlases are based on chunks of information, not on one coherent frame, and if an experimentalist comes to them with a dataset that traverses a lot of these chunks, an important question is, are they aligned properly or are there going to be problems if it is integrated into the system? Sometimes, for instance, a part of a cell runs through a region of the brain about which there is nothing currently atlased, in terms of metrics or references. It certainly should not be assumed that what is currently incorporated is 100% accurate, because some of the reference systems were devised as local references, not as absolutes, and were never made for this new kind of work.

Moreover, it seems that much modelling work has difficulty handling spatial information. Models are usually able to handle spatial files, which are relative to a brain area, but they get in trouble when they are required to work within the absolute coordinate system of an atlas. How much manual adjustment is carried out by the modellers is hard to evaluate. In particular, there are experimental issues that modellers have trouble coping with. For instance, depending on the processing methods of the brain tissue, there are different deformations of the brain. A lot of the normal histology at present is based on a standardised process for which everybody knows what the transformation factors are along x, y and z. This process has been tested and run for the last four or five decades. When a new method like CLARITY¹³ is developed, and the transformation factors are affected, there is no easy transformation for aligning the datasets resulting from the different methods. An anatomist is likely to be able to identify the correspondences, where a chemist or a computational modeller may not. The result is that modellers may complain that they are being given mutant brains, when it is the processing method that causes the discrepancy and there is nothing wrong with the data. This is an area where the ‘bridging’ role of the individuals operating the Neuroinformatics platform could help provide interesting solutions.

Knowledge management is a key objective of SP5: ensuring that the ontologies¹⁴ are maintained keeping the latest concepts up-to-date and pointing to the latest supporting data, models and literature. During our workshop at the Fondation Brocher, a data scientist in the HBP Neuroinformatics team gave an overview of the Knowledge Graph—the conceptual design of the knowledge base—that they would like to achieve for the Neuroinformatics Platform, taking on board the “zoo of data out there” of many different types, at many different resolution scales and timescales, produced through many different experimental techniques that the HBP wishes to integrate. Their core challenge



is how to create the metadata in order to make the data discoverable, accessible, usable, publishable and citable. Six broad categories of metadata have been retained: observations and models, specimen, contributors, location, methods and protocols, and disease. The Neuroinformatics team has chosen Provenance, a form of structured metadata designed to record the origin and source of information, which is useful for evaluating whether data can be trusted, for integrating it with other heterogeneous data sources, and for crediting attribution to the data creators throughout the data life cycle. They are using PROV, the standard Provenance model of the World Wide Web Consortium (W3C). A further presentation complemented this theoretical presentation by illustrating through practical examples how the data integration proposed by the HBP Neuroinformatics Platform could work, how the data model could help manage the data life cycle, and of the benefits it could bring to laboratories.

Standardisation

Part of the roadmap for the Neuroinformatics Subproject is that it will collaborate with other existing and future initiatives (prominently the International Neuroinformatics Coordinating Facility or INCF) to develop global policies and standards for data, ontologies, nomenclature, data preservation and data sharing.

Almost a century ago, Albert Whitney argued that although the idea of standardisation may convey a sense of immobility and rigidity, it is actually a necessary stage in the process of innovation (Whitney, 1924). This has since been recognised as a major insight by historians of technology, even those who do not share Whitney's unbounded enthusiasm for the benefits of standardisation (Russell, 2009). If this is indeed the case, then it is all the more important to examine the various dimensions of standardisation and the questions they may raise, in relation to the Human Brain Project.

If we trust John F. Sowa's 'Law of Standards', top-down definition of standards does not work well: "whenever a major organisation develops a new system as an official standard for X, the primary result is the widespread adoption of some simpler system as a *de facto* standard for X."¹⁵ Further, it is widely acknowledged that first movers, if they are big enough, set their own standards. However, in systems biology, most standardisation initiatives have been community-based and multidisciplinary, and many of the most successful initiatives have become *de facto* standards without going through official approval procedures (Brazma *et al.*, 2006). It was thus strongly suggested at the Fondation Brocher workshop, by participants external to the project, that the HBP should be as open as possible and that a motto should be 'release, release, release'—and in the most user-friendly way possible. While participants recognised that some, perhaps more senior investigators, had reservations about such openness and the related priority of engagement with the community, most felt that the example of the Allen Brain Institute shows the benefits of the open approach they have adopted, and this can provide a powerful example showing the value of openness.

Data formats can be thought of as analogous to product standards which ensure the delivery of products that can be exchanged and integrated with similar products: they "create both a need for more careful production and a need for evaluation of the finished product, changes that may disrupt existing work practices." (Slaton and Abbate, 2001). Standardisation, although not an end in itself, becomes increasingly important in a high-throughput era dominated by data production on an industrial scale—and we have already evoked the kinds of changes and disruptions that this could cause to work practices.

But the development of procedures and standards to facilitate data integration has other implications than simply changing work practices, or as we have explained in a previous section, reconfiguring power relations or displacing labour. For Sabina Leonelli,¹⁶ whose research focuses on the philosophy, history and sociology of data-intensive science, the choices leading to the specification of infrastructure and standards for data integration



have a bearing on the epistemic goals that can be achieved and thus on the forms of knowledge that will be produced. Conversely, “prioritising specific epistemic goals over others might lead to structuring data integration, and the infrastructures and standards used to that effect, in different ways.” She argues that “[d]ata integration and the production of scientific knowledge ... are strictly intertwined: a crucial question for scientists and philosophers is exactly in which ways do the worlds of data infrastructures and knowledge production inform each other, and how institutional contexts and epistemic goals affect the development of data integration strategies in contemporary biology” (Leonelli, 2013).

This highlights the importance of the curatorial work that goes into the design of the data models and associated metadata— work that requires a comprehensive understanding of how and by whom the data might be used, and that much thought be given to the classification and specification of datasets so that they become compatible and usable. Indeed, Leonelli insists that “[d]ata curation constitutes an integral part of processes of discovery, where conceptual and practical decisions about how to integrate and visualise data affect the form and quality of knowledge obtained as a result” (Leonelli, 2013).

Here we run into an issue that we have already raised as crucial for predictive neuroinformatics, which is the lack of consensus on what counts as meaningful categories of components in the brain. Just looking at neurons, we find that there is disagreement on approaches to classification: subdivision by structure, by different functions, by gene activity, by a combination of multiple factors. There is a deep fracture line, apparently going all the way back to Cajal, “between ‘lumpers’, who tend to focus on commonalities between neurons, and ‘splitters’, who tend to divide cells into many subcategories based on subtle differences” (Underwood, 2015). Indeed, during our workshop at the Fondation Brocher, one of the participants made his position clear by declaring during his presentation: “I tend to be a ‘lumper,’ other people in this room are ‘splitters’.” There is even disagreement on the very possibility of classifying neurons, with some thinking that it is possible but that we do not have the right data yet, and others being convinced that classes of neurons are artefacts that do not correspond to natural kinds. Among those who believe in the possibility of classification, some are attempting to automate the process with machine-learning algorithms crunching masses of data. We must also accept that even if a consensus is achieved on neuron classification, it is not clear what the result will provide (Underwood, 2015). As was pointed out by one participant at the Fondation Brocher, the full taxonomy of ‘*Caenorhabditis elegans*’ nervous system has still not yielded much insight about the ways it generates behavioural functions, despite being fully mapped for two decades. In this context, designing an integrative data infrastructure appears fraught with thorny problems as no single set of design choices will satisfy all of the neuroscientific community.

A last issue worth mentioning in relation to standardisation, especially in view of the move towards industrialisation discussed earlier, is the risk of disproportionate production of certain kinds of data, typically those that are easy to produce and amenable to ‘mass production’ by the ‘industrial labs’. This can freeze a data infrastructure into accepting only certain kinds of research data and thus into exploring only certain types of data; it has been observed that this risk is especially present when data is not generated to answer specific research questions (Leonelli and Ankeny, 2015).

Data-consuming models and community efforts

We have evoked the general aims of integrating data for Future Neuroscience, of scaling small data through data infrastructures, but so far we have said nothing of how these datasets are used. This is where their paucity becomes tangible as modelling, especially of the data-driven variety, is data-greedy: data are needed for developing the models, for parameterising them, and for testing them against control cases by running simulations, before the models can be used for prediction.



The Brain Simulation Subproject (SP6), building on the work of the Blue Brain Project at EPFL, is primarily geared towards developing data-driven, biologically realistic brain models. It follows a bottom-up approach aimed at making it possible to achieve a mechanistic understanding of brain function. SP6 has three objectives, of which the first is to establish a generic strategy to reconstruct and simulate the multi-level organisation of the brain for different brain areas and species. The second is to use this strategy to build high-fidelity reconstructions, first of the mouse brain and ultimately of the human brain. The third is to support community-driven reconstructions and simulations and to support comparisons between models based on different tools and approaches. It will integrate the tools and workflows it develops in a Brain Simulation Platform, which it will operate as a community resource. The platform will provide tools and services for the collaborative reconstruction and simulation of the brain, models of different brain areas and whole brains (including models developed outside the HBP), and tools for *in silico* experimentation, supporting comparisons between different models and approaches.

For models, as for data, sharing and collaborating have emerged over the past months as a favoured strategy for the future of the Human Brain Project. This was a key issue raised for both the Neuroinformatics and the Neuromorphic Computing (SP9)¹⁷ Subprojects at the Brocher workshop. Discussion focused on the need for collaboration, and why community was essential for neuroscience research in the near future. The main issue for a number of participants is that it is impossible even for a large research group to envision developing, simulating and validating an accurate and complete model of an entire mammalian brain. Getting there will require the collaboration of individual scientists, and both small and large research groups. It will require community models, community databases and community tools. Over the past few years, there have been real efforts in these areas, but not so much in the development of community infrastructure projects. For instance, GitHub, the largest code host in the world,¹⁸ is not tailored to the specific needs of the wider neuroscientific research community. The Open Source Brain,¹⁹ supported by the Wellcome Trust in the UK, is another. A major problem of such infrastructures is their need for ample computer power and resources, as well as long-term support: the HBP could have a role to play in this respect. The challenge is how to get tool developers, infrastructure architects, diverse schools of modellers, and experimentalists from different traditions, to work together.

An experimental initiative in open collaborative modelling has been launched by a group in the Simulation Subproject (SP6) around the area known as Hippocamp CA1 in the mouse brain. They started from the premise that community approaches are difficult to achieve, and there is no proven recipe to build a collective approach. They also made clear that there were various levels of collaboration possible between research groups, the looser being *ad hoc*, but that they were aiming, hopefully, for a more engaged community effort, a ‘coordinated push’. They organised a two-day workshop held in London, 31st March-1st April 2015, which kick-started the experiment. They presented the rationale and aim of the meeting as follows:

“Hippocampus CA1, a brain region fundamental for learning and memory, is one of the most intensely studied brain areas world-wide. This means an enormous quantity of data, but also heterogeneity in terms of sources, methods, quality, etc. Integrating the available anatomical and physiological data in a unified model of hippocampus CA1, and validating it broadly against known phenomena, is a challenging but feasible perspective given the HBP platforms roadmap.

In short, the aims of the workshop are two-fold. First, to engage the larger community of experimentalists and modellers working on hippocampus, and highlight existing modelling efforts and strategic datasets for modelling Hippocampal CA1. Second, to define and bootstrap an inclusive community-driven model and data-integration process to achieve open pre-competitive reference models of hippocampus CA1, which are well documented,



validated, and released at regular intervals (supported in part by IT infrastructure funded by HBP).”²⁰

The advice given during the wrap-up of the Hippocamp meeting by a participant, external to the HBP, who has been involved for many years in open science / open data projects in neuroscience was to stick to a set of key principles:

“- Be open

- Be inviting

- Be clear on goals

- Make sure data that the model is based on is freely available

- Make code and models easy to install

- Make code and models accessible to non-computational researchers

- Lower barriers to getting to something useful & scientifically valid/interesting running on someone’s machine”²¹

One conclusion following from the HBP Hippocamp CA1 initiative and from further discussions during our workshop at the Fondation Brocher is that perhaps the most fruitful level to initiate collaborations between HBP researchers and those in other initiatives is not at the level of Principal Investigators (PIs) but at what was referred to as ‘PI minus 2’ around practical use cases such as a specific brain function or a specific brain area. Having more initiatives like Hippocamp CA1 might thus be very successful in the short to medium term. These initiatives may not take place around the core activities of a lab, but could be initiated and managed by someone other than the PIs in the form of quick and agile work programmes. Those can move forward with collaborations among researchers who are happy to be open, and might produce results. A good way to engage the community and move forward might thus be to encourage such low level initiatives which do not depend on strategic decisions at the very top. As a complement and alternative to changing things from the top with strategic decisions on collaborations, pushing things forward from the middle might be a productive approach.

The advice that code and models should be easy to install and accessible to non-computational researchers chimes with a concern that was raised during the workshop at the Fondation Brocher, which is the need to ensure that the design of the HBP Platforms does not exacerbate the digital divide between the computational neuroscience community and the rest of the neuroscientific world. The working group which discussed this issue came to the view that close attention should immediately be paid to all the different categories of potential Platform users; it was suggested that the HBP should ‘be more like the Brain Allen Institute’, for example in the way that their website is set up, to make it easy for diverse categories of users to find what they are looking for, and even to find material that they could use but were not aware existed.

Open community, open data and open science: Issues of ‘open’

Although there are many expected benefits to ‘openness’, there has been little critical investigation of practical case studies so far. At this point in time, three broad types of critiques have been levelled at the ‘open data’ phenomenon: “... open data facilitates the neoliberalisation and marketisation of public services; it promotes a politics of the benign and empowers the empowered; and it lacks sustainability, utility and usability.” (Kitchin, 2014: 61)

These general classes of critiques can probably be extended to ‘open science’. In particular, it may be argued that in the case of publicly-funded research like the Human Brain Project, opening science and data may lead to privatising the results of research, which is then available to be taken up in commercial and for profit developments in the



interest of a few, while the research process as a whole, together with its inevitable failures, are mutualised across European citizenry through their taxes.

During our workshop at the Fondation Brocher, and at the Hippocamp CA1 meeting in London, open science and open data were repeatedly advocated, and often set against the more traditional Intellectual Property Rights regime, which many felt to be the one embodied in the HBP and encouraged by the European Commission. Our own view, however, is that the issue is more complex. Certain forms of ‘openness’ fit very well with re-framed approaches to Intellectual Property, and we recommend that there be an in-depth discussion of these apparently conflicting aspects of the project, so that the ‘openness’ of science and data in the HBP will give priority to providing benefit to those who fund it.

3.2.2 Bridging scales

Modelling issues

The compatibility of models is a major issue in neuroscience. There have been some efforts to facilitate compatibility. For instance, a few years ago, an international group of researchers collaborated using an Open Source software approach to develop NeuroML, a neuronal model description language that enables detailed data-driven models of neurons and their components to be defined in a standalone form, allowing them to be used across multiple simulators (like NEURON or NEST) and archived in standardised format (Gleeson *et al.*, 2010). Although this was a very concrete step towards compatibility, it has only partially managed to solve the thorny problem that the specialised languages employed by neuronal simulators are in general not interoperable, which limits the re-use of model components and cross-simulator validation. But models are incompatible for more reasons than the language in which they are developed. For instance, modellers can model neurons at different levels of resolution, and use different kinds of variables to describe the same types of neurons at the same level of resolution, depending upon where their interest resides. The proliferation of models is indeed why part of the plan for the Neuroinformatics Platform is to develop a repository that will index a wider range of models than those developed in, or made accessible through, the Brain Simulation Platform.

It is easy, but over simple, to portray disagreements among neuroscientific modellers in terms of a conflict in which ‘top-down’ approaches are pitched against ‘bottom-up’ partisans. As explained earlier, the Simulation Subproject itself has adopted an approach that can be termed data-driven science, which looks to generate hypotheses by letting them ‘emerge’ from the data, in contrast to the tradition of theory-led empiricism which postulates hypotheses and seeks confirmation through experimental data (Kelling *et al.*, 2009). Some have argued that data-driven science “seeks to hold to the tenets of the scientific method, but is more open to using a hybrid combination of abductive, inductive and deductive approaches to advance the understanding of a phenomenon” (Kitchin, 2014). In neuroscience, typically, cognitive and systems neuroscience have been characterised as using a top-down approach, starting from observed behaviour and functions, as opposed to an approach which begins from detailed, more biologically realistic, modelling.

The apparent opposition between ‘top-down’ and ‘bottom-up’ approaches was at the heart of the scientific criticism of the Human Brain Project in July 2014, leading to the EC review and the mediation process, and to the current scientific re-focusing of the project (see Section 1.4). However, it is preferable to see the relation between the two approaches as complementarity rather than as opposition, and in our discussions most participants have been keen to overcome partisan taking of entrenched positions. Indeed, relations between diverse approaches have been the subject of much discussion both within the project and between the project and external stakeholders, such as at the



Hippocamp CA1 workshop and our workshop at the Fondation Brocher (such debates have been widely discussed, see, for instance, Eliasmith and Trujillo, 2014).

Our Foresight work suggests that the challenge for the Human Brain Project infrastructure (the human dimension *per se* is addressed in Part 3 of the report) is to help overcome fragmentation, and dissention, while preserving a pluralism of views and approaches—and in particular, to make space for a plurality of approaches in attempting to bridge between the Human Brain Project and clinical neuroscience. It is in part with this challenge in mind that for the Operational Phase of the project, the Cognitive Architectures Subproject (SP3) is being re-organised as "Systems and Cognitive Neuroscience", to try and occupy a federative role within the project, linking the other Subprojects of the Human Brain Projects by addressing ambitious cognitive and systems neuroscience questions.

Terra incognita

The Hippocamp CA1 experimental initiative in open collaborative modelling has made it clear that in neuroscience, *intra*-level integration between distinct research fields is already a challenge. Things get significantly more difficult when attempting *inter*-level integration and in fact, it appears that—until recently at least—most cases of multidisciplinary integration in neuroscience were cases of intra-level integration (Craver, 2005). Leonelli, who has studied cases of inter-level integration in the field of plant biology, has observed that in such cases, which bring together data produced by diverse research specialties at various levels of organisation of the same plant, “most of the research efforts focus on finding ways to overcome disciplinary barriers, such as difference in methods and terminology between molecular and cellular biology, in order to collect and visualise those data within a single framework”. The impact this has in terms of epistemological goals and forms of knowledge produced (see above, section on *Standardisation*) is that “biologists involved in those efforts have tended to prioritise mechanistic understandings of organisms over the study of biodiversity” (Leonelli, 2013).

Bridging scales in brain research—the strategic goal of the Human Brain Project for Future Neuroscience to “achieve a unified, multi-level understanding of the human brain that integrates data and knowledge about the healthy and diseased brain across all levels of biological organisation, from genes to behaviour”—is indeed very much about inter-level integration. And it may be rather problematic to achieve if some important dimensions of the brain are not well represented and addressed in the plans of the HBP, especially plasticity and neuromodulation.²² For this may be a case, as with Leonelli’s plant biologists, where model and infrastructure design may lead to privileging certain epistemological goals and forms of knowledge.

But the challenge is not just about inter-level integration. Coming back to the Simulation Platform, its plan is that in the first five years of the Project, the core team will develop and validate its tools and strategy in mouse—the species for which most data are available. Its goal is to build a scaffold model of the cellular-level organisation of the mouse brain. In the following five years, it will aim to produce a scaffold model of the human brain, and this work will involve the integration of sparse data from the human brain with data inferred from non-human primates, mouse, and simpler animals. Cross-species integration is thus also part of the challenge, and according to Leonelli, evidence suggests that this will complicate matters further, as the demands and goals of working across species may compete with those of inter-level integration in a single species (Leonelli, 2013). Problems specific to cross-species integration were discussed both at the Hippocamp CA1 workshop and at the Fondation Brocher. Participants discussed the problems related to ‘mousing’ the rat—the fact that much of the data coming in under the mouse part of the project (SP1) will in fact be coming from rats, so that data coming from specimens of different species at different stages of maturation will have to be managed and reconciled—and to ‘humanising’ the mouse.



The working group that focused on bridging scales during our workshop at the Fondation Brocher pointed out that this has repeatedly been highlighted as one of the major problems— and the most complex scientific problem—not just in the HBP, but in neuroscience in general. In order to move the problem forward, the group isolated what they considered the key issues:

- 1) Comparison between different species. It is a strategic objective. With the HBP moving towards a focus on infrastructure and generic tools, limiting species to the mouse and the human in the Ramp-Up Phase should be lifted. Groups working on all possible animal models must be able to use the Platforms. This also raises the question of the relationship between the HBP and the other brain projects, which work on different species. Possible complementary strategies should be explored.
- 2) The validity of predictive reconstruction—of extending datasets algorithmically. It is a key scientific approach used in the Blue Brain Project laboratory, and it is an important scientific discussion that the HBP needs to be part of.
- 3) What theoretical approaches can be used to bridge scales. There is already a Subproject in the HBP dedicated to theory, but the HBP needs to address this further, ideally working with diverse communities working at different brain scales.
- 4) Tools developed for the HBP Platforms need to have specifications for the data they can accept.
- 5) There are other possible directions to explore. A first step towards bridging scales could be to get research groups from different research specialties currently working in isolation to start collaborating. The Neuroinformatics Platform and its team can play a role in facilitating this, as was demonstrated during our workshop at the Fondation Brocher. There, they presented the ways in which the data model they have developed could help integrate experimental work, analysis and modelling/simulation done by research groups from different Subprojects for end-to-end reconstruction.

In the same vein, by identifying complementarities between different research groups and acting as broker between them, the Neuroinformatics Subproject could kick-start collaborations around well-defined cases. In particular, during the Expert Seminar entitled “Theory and data for advancing Future Neuroscience and the Human Brain Project”, which took place on 21-22 May 2015 in Paris, and was organised by the Danish Board of Technology Foundation in collaboration with the European Institute for Theoretical Neuroscience (SP4), the High Performance Computing Group Subproject (SP7) and the Researcher Awareness Group (SP12), it was suggested that the Human Brain Project should try and emulate successful examples that combine top-down, hypothesis-led approaches with bottom-up, data-driven ones. A proposed exemplary case is that of the work on the visual system of the barn owl by Eric Knudsen’s group at Caltech (Sridharan *et al.*, 2011).

We mentioned earlier that the design of the HBP Platforms should be careful not to exacerbate the digital divide between the computational neuroscience community and the rest of the neuroscientific world, and maybe that the HBP should ‘be more like the Brain Allen Institute’, whose website makes it easy to find things. This is also relevant for the challenge of bridging scales. To start collaborations on specific use cases that try to bridge scales, different schools of experimentalists and modellers will need to come together, and the HBP infrastructure should play a positive mediation role; ‘findability’ is going to be key. There needs to be a focus on the user interface question—how to navigate the HBP Platforms, how to find other groups, models, datasets, etc. This requires serious thinking, and so do some of the enabling technical solutions that have already been proposed. Indeed, as the working group that discussed this particular question during our workshop at the Fondation Brocher pointed out, some of the elements of the HBP user access infrastructure are worth opening to scrutiny and questioning. Monitoring APIs,²³ for



instance, involve complex flows of metadata that can potentially be used in many different ways, some of which unforeseen, which are worth interrogating.

Practical steps

A number of concrete actions were recommended by the working group focused on bridging scales during our workshop at the Fondation Brocher.

First, with regard to model development, there are plans to build a workshop series into the agreement for the next phase of the project (Specific Grant Agreement 1). It should involve specific groups in the HBP (Theory, Simulation, and also components from Neuroinformatics Platform) and the respective communities outside of the HBP. The provisional title of the series is “Systems Neuroscience: Scientific Integrity in Data integration”, where integration is meant to span scales and close gaps. The aims of the workshop series are better scientific agreement on standards for these questions, and a better sense of validity of the science being pursued.

Second, with regard to tool specification, the discussion made it very clear that there was a need for an improved validation protocol to be implemented with respect to the incoming data. This would include a specification of the data that is coming in, a specification of some of the properties that they have, and validation before actual implementation in code. One concrete scenario that is envisioned is a workshop which picks a specific tool, brings the potential community to the tool, helps them make their data work with the tool, and if it fails, to try in the same session to encode the validation check in the code. The aim is to produce better tools.

Bridging with the clinic

Ultimately, it is hoped that clinical neuroscience—psychiatry and mental health—will be the area of application that will most benefit from successfully bridging scales. During our workshop at the Fondation Brocher, one of the working groups investigated how neuroscientific modelling could be made relevant to clinical practice. It considered what could be done, within and outside the HBP, to move to a more collaborative relationship with European stakeholders and clinicians, and to increase trust in the HBP within that wider community. As well as considering issues of standardisation that we have discussed earlier in this report, they recommended HBP action in three directions to achieve this.

The first concerned the HBP Medical Informatics Platform (MIP), developed in Subproject 8. Participants argued that the HBP needs to find ways of publicly demonstrating how the MIP could address the challenge of brain disorders. In order to achieve this, they recommended that the HBP should try and link the MIP more closely to four groups of stakeholders. These groups are: European parliamentarians, so that they understand and trust what the MIP is doing; organised groups of scientists, for example the European Brain Council and the European Neuroscience Society, so that they are supportive and collaborate with the HBP; patients and patients groups, who will respond best to modest and realistic assessments of how the MIP might benefit patients in the future, and the likely timelines, so that they will be more willing to share their data; and in the European data space, especially with others who are seeking to use ‘big data’ for clinical research.

Second, participants argued that it was advisable for the HBP to look beyond the MIP, whose approach to modelling brain disorders is based on mining large quantities of clinical data without initially dividing by diagnosis. It was suggested that the HBP collaborate with those using other approaches, for instance groups that start from the challenge of particular disorders and how to model them. This would require involving a wider group of practitioners, including clinicians and epidemiologists. In the view of our participants, the key to collaboration was to start with the things that clinicians hoped an initiative like the HBP might provide. One key priority for clinicians is support for differential diagnosis of brain disorders. A second revolves around rare diseases, where often individual research



groups and clinical practices have only a few cases—there is a need to build up a big enough dataset on rare neurobiological or brain disorders to enable analysis on powered-up samples. A third priority is to support better drug and therapy development. This is a longer term issue, which raises difficulties with regard to commercialisation and ownership, and would almost certainly require the development of relations with pharmaceutical companies.

Third, participants pointed out that there are unexplored troves of data collected by teams who were already funded by the EU, in areas like traumatic brain injuries, stroke, or epilepsy (for example, the EPICURE project²⁴). The HBP could perhaps contribute to the analysis of that data and the standardisation of data formats.

For such partnerships to develop, data collecting groups must have an incentive to become involved with the HBP. One suggestion was that there may be sources of funding within the EU where groups who were funded to collect data can apply for the curation of the data and for training purposes, in order to maximise data usage. Another incentive for the groups concerned would be the opportunity to get back bigger data and better algorithms. What was key, in the view of participants, was that the HBP should not position itself as leading all these developments, but rather should place itself at their service, to help them and work together.

4. Building a Community for Future Neuroscience

4.1 Background

How will different audiences understand the Human Brain Project at the end of its ten-year lifespan? At its launch, the HBP was presented as a ‘big science’ project with emphasis on the multi-scale simulation of the human brain. As the project draws in more participants from the experimental neuroscience community, and as the direction given from the EC and scientific reviewers begins to focus the component projects of the overall HBP towards integration, the HBP must re-evaluate its links with the wider communities within which it works. As we have already discussed, the outcome of the various reviews of the project that have taken place over the past year is to place increasing emphasis on one aspect of the HBP that was always part of its ambition—that it should be an infrastructure project to provide crucial data integration, data curation, and data analytics tools and computing resources to the neuroscience community as a whole. In this sense, the HBP may come to be seen not so much as doing big science as enabling big science to happen. This does not mean that important scientific results will not come out of the immediate scientific community most closely associated with the HBP. Nor does it imply that the task of building an infrastructure project does not in itself require difficult scientific work. Indeed, the scientific decisions required in order to build a flexible yet robust infrastructure that enables further scientific advances will themselves be very challenging. It does imply, however, that the HBP will come to be seen not so much in terms of the results that the HBP produces itself, but in terms of the scientific findings that its infrastructures and tools enable.

If this is the case, the relations that the HBP develops with various audiences, and with various user communities, become crucial. These audiences include the public at large, the clinical neuroscience community, entrepreneurs in the computing and clinical health fields, public policy makers, and many more. But for the purpose of this report we will consider primarily the experimental neuroscience community, the computational neuroscience community, and to some extent the clinical neuroscience community. Arguably, these are the communities whose involvement is initially the most important to the success of the Human Brain Project as a whole. For this reason, we will focus upon how



the HBP can build its links with this community. Many of the factors that will determine the success or failure of these neuroscience transitions are the social factors involved in building a neuroscience community that can take advantage of what the HBP has to offer. It is to these challenges that we now turn.

4.2 Emerging Challenges

In considering challenges such as building a Future Neuroscience community, it is quite common to separate the technical and social as if these were two distinct issues. However, the social and technical aspects of the Future Neuroscience considered in this report are quite interlinked. One might think of them as two sides of the same coin. While a neuroscience laboratory may be thought of, in one sense, as an array of technical procedures, routines, protocols, experimental and statistical practices oriented towards producing data, interpreting it, and generating results in the form of papers or models, it is clear that all these activities entail multiple craft skills, complex relations of power, authority and prestige between the participants, styles of thoughts shared among a community of specialists and much more. These not only account for many instances of ‘failure’, but also have to be correctly aligned if the outcomes are to be considered ‘successes’ by participants and their peers (Fleck 1935, Latour and Woolgar 1979). While we often, in everyday language, attribute some successes to the technical, and some failures to the social, in reality the two are intertwined—this is why some analysts speak of socio-technical systems (Bijker *et al.* 1987, Law 1992, Trist and Bamforth 1951). There are few situations that do not exist in both registers: what people do always underpins the technical possibilities of a situation and, reciprocally, the physical, material, and technical surroundings of a situation both provide and limit the range of social possibilities.

In the previous section, we looked at what might initially be thought of as technical issues within the neuroscience community and pointed to the relevant social aspects of the situation. In this section, we will look at what might initially be labelled as social concerns. While many of these concerns relate to previously discussed technical issues (data scaling, bridging scales), here we engage more generally with building a community for Future Neuroscience. In addition to outlining the challenges of doing so, we will examine the material, technical and institutional frameworks (and in some cases conceptual frameworks) that might influence the community building outcomes. Just as there is no such thing as a technical issue that cannot also have a social aspect in need of consideration, every social situation has material, technical, institutional parameters within which it is framed and can be reframed.

We will focus on three issues in this discussion:

- Building trust for a data sharing community
- Working in an interdisciplinary manner to solve new problems
- Researcher awareness.

4.2.1 *Building trust relationships, incentive structures, cooperation and infrastructure*

The scaling-up of data collection, processing, and analysis requires much personal interaction. While there are many material infrastructure decisions to be made about how to best handle the data, these are ultimately influenced by the way in which (and if) members of the experimental community choose to bring their data and experience to the project. The HBP must consider the choices it will make to enable data sharing and the resources it will set in place to be of use to the experimental community. Most of all, trust is required between groups if they are to believe that working together will be mutually beneficial, and that data sharing will be both fair and produce valid scientific results.



Existing recognition of the social science of science

The idea that a cultural shift within the neuroscience community towards the sharing primary of data is necessary for scientific progress is not new (Koslow 2000, Mazziotta *et al.* 2001). Nor is the recognition that this will require careful “attention to the sociology involved” (Mazziotta, 2001 p.1316). The emphasis on data sharing sees neuroscience as following a larger trend of computer-enabled biology already begun in subfields such as genomics and proteomics (Koslow 2000).

Many of the personal factors contributing to individual scientists’ reluctance to share data have been recognised in existing neuroscience literature (Koslow 2000, Mazziotta *et al.* 2001) and discussed earlier in this report (see ‘sharing data’ Section 2.2.1).²⁵ Furthermore, there is a clear recognition that incentive structures are important. In our fieldwork, this was most apparent in our informants’ firm belief that the work of data curation or code creation should be rewarded, and that in the present system it was not always acknowledged. For example, one suggestion was that those writing important software code necessary for analysis could be acknowledged in the authorship of publications, the most common currency of scientific recognition. A second suggestion was that there could also be ways to acknowledge the creation of sharing of data on the CV of the researcher involved. It was pointed out that such recognition is particularly important for early career researchers.

Sharing data: the sociology

Regarding the research group involved in the creation of experimental data, there are many reasons for which they may wish to keep their data for themselves (see ‘sharing data’). In the scientific literature, such concerns of individual scientists or labs are often addressed by a moral appeal concerning the goal of scientific progress. To the concern ‘Someone may find something new in my data,’ Koslow suggests, “finding something new in an existing data set will increase our scientific knowledge without the unnecessary effort and cost of repeating the entire experiment.”²⁶ While this response is certainly true, it does not address the basis of the resistance to sharing among individual researchers and the ways that they experience and understand these issues of data sharing. A study of neuroscience community attitudes by the Centre for Biomedicine and Society (2013) finds both perspectives present:

“Data ‘hoarders’, or those who are coy over the full interpretation of the results, are to be avoided. Yet such practices are only frowned upon if they are done to the researcher in question, not *by* them. “*You don’t want to give everything away otherwise you’ve got nothing for yourself*”.” (emphasis in the original)

However, participants in our fieldwork were of the view that, with appropriate incentive structures, the common good of scientific progress need not be pitted directly against the individual interests of, and a sense of fairness to, the individual scientist. In addition to acknowledging those responsible for data creation in the authorship of scientific papers, and finding ways to include this in CVs, other options were also proposed. As discussed below, it was argued that the creation of data should be recognised in provenance structures that record the origin of the data. Certain data creators might thus achieve a reputation for producing high quality data in a specific field.

While discussions about incentives in the scientific community are important, not all contributions in any community are the direct result of this kind of exchange. In some cases, the simple reward of participation in a shared community of concern is sufficient, and consciously or non-consciously, participants recognise that giving and sharing with others are crucial to consolidating their membership of that community (Mauss 1954, Graeber 2011, 2001, Dillman 1978/2014, Blau 1964, Homans 1961, Thibaut and Kelley 1959). Therefore, the simple ability to acknowledge contributions within the community may be sufficient to encourage data sharing in a community that already has a reputation



for fairness and reciprocity of exchange. This sense of individual community membership and its obligations and rewards may also be linked to a more general commitment to scientific progress within that community, as, for example, suggested by Koslow above. A shared commitment to scientific progress and the benefits it may bring thus needs to be nurtured, in parallel to an attention to incentives, a general concern for fairness, appropriate levels of resource to meet the basic needs of research community members, and more ways to acknowledge contributions. In all these matters, it is particularly early career researchers who are most in need of support. As we have discussed in the previous section, this is both a social and a technical challenge—building a data sharing system that resolves some of these concerns rather than exacerbates them is key to the success of such an initiative.

The validity of data outside its experimental context

In addition to the concerns that one research group might have about sharing their data there are also the concerns that another research group might have about receiving such data. Many researchers believe that data is dependent on the methodological and experimental context that has generated it. How will they know that the data is of good quality and collected in a relevant and comparable way to how they as a team would be using it to address a particular scientific question? More generally, when data is contributed from different experiments and combined, then analysed, how can one trust the validity of the combined analysis results? We have discussed this issue in the previous section—it is both a technical one concerning standards and protocols, and a social one concerning mutual trust.

The fact that experimentalists are very sensitive to validity questions in the use of data (specific to its experimental situation) has contributed to a perception among some in the neuroscience community that computational neuroscientists and modellers, who are often neither neuroscientists nor even biologists, often do not possess the relevant biological knowledge to make useful contributions. One informant in our research challenged the paradigm that more data (and more sharing of data) was all that was needed for progress in neuroscience. To paraphrase, ‘more garbage in, more garbage out’. Researchers thus need to consider a range of questions regarding how data is collected and under what circumstances (and by whom) before they can judge the validity of using that data to answer a specific question. For this reason, computational neuroscience will need to have a greater interdisciplinary recognition of what it needs to provide to be genuinely useful to experimental and clinical neuroscience.²⁷ Hence the technical system design is part of the material frame within which data validity judgements of the community will play out: it must consider not just how data can be shared across a community, but also how it can be trusted within that community.

Provenance structures for data sharing and community trust

One solution for such concerns about sharing data might be found in the structure of data sharing standards, in particular through the use of metadata, giving contextual information about the experimental source and conditions of producing the data. This is known as the provenance of the data.²⁸ Metadata can include not only the name of the laboratory and experimentalists who created the data, and the date of creation, but also specific details of the ways in which the data was collected, the protocols used, the methods for signal collection and analysis, and so forth. It may, and probably should, include details about the experimental context, and ideally the entire workflow of the experiment (paired with by linking or within the data file itself) by annotation.

Indeed, such metadata is not only key to collaboration and sharing of data between research groups, but also within research groups—metadata plays a key role in making data more likely to be shared, because the necessary contextual information is present in or paired with the data file. An experimentalist may want to share the data with students, or



may receive and use data created by students, or may want to use data that the experimentalists themselves created in a previous year and to which they need to return. The initial context of the laboratory thus needs to be considered first, to understand how data is used, annotated, passed around, or stored. As one presenter at our Brocher workshop made clear, practices within the lab become the basis upon which the data is marked, and thus the basis upon which data markings either facilitate, or are inadequate for, the sharing of data. Often there are working assumptions and local knowledge within labs that are shared but implicit. But where these are made explicit, and where routing laboratory practice requires routing collections of metadata, those data are also more available for sharing between labs. To the extent that automated metadata annotation can happen within the experiment, the researchers will not have to manually annotate data before it can be shared. This therefore facilitates data sharing by reducing time and labour barriers to annotating data so that it is of sharable quality. An automated metadata recording with a standardised set of annotations would include more contextual information than might be considered necessary for local sharing: exactly what and how metadata is collected is currently a matter under discussion, as we have considered earlier in this report. In the case of data uploaded to a public repository, the provenance of the data will contain information that links it back to its original creator. Thus a user of that data might be able to get in touch with the data creator, and make further inquiries about the initial experimental context. This facilitates use and reuse of data, and may in some cases enable new collaborations.

Proper provenance via metadata also allows scientific credit structures to be extended back to the various participants in data creation, rather than reside only with the analyst of the data who authors a scientific paper. In this way, a variety of junior roles often occupied by early career academics within the overall research process can be acknowledged, potentially contributing to a greater sense of community contribution and acknowledgement. A good provenance structure might help to address some of the concerns about sharing data and developing trust with the neuroscience community. It could do so by enabling contributions of any kind to be labelled and potentially acknowledged, either within a direct incentive structure (rewards for work), or less tangibly within a culture of social exchange (participating in mutually beneficial sharing). Within an effective provenance structure, the epistemological relevance of certain data to answering certain questions can be estimated. The ability to contact the original data creators might facilitate further validity checks and increase trust in conclusions based on new method innovation in computational neuroscience.

There are also potential opportunities for the misuse of provenance structures. Our informants imagined situations where competing labs might scan provenance to gain intelligence on their competitor's methods, insights, and weaknesses. Provenance structures could be used uncharitably by employers as a metric for judging and enforcing lab employee productivity. To the extent that provenance information is also always data about the individuals who contribute data, it might even come to be considered personal data which could be exploited, and thus require some degree of protection (even potentially subject to European data protection rules). These issues of potential misuse led to discussion amongst our informants about different types of data provenance information, and how widely certain types of data provenance should be circulated; they demonstrate again the intertwining and inseparability of social and technical issues in community building.

Building collaborative initiatives

There are multiple models for building collaborative initiatives. Top-down, bottom-up, and 'pushing forward from the middle' were all potential approaches discussed by our informants. The different approaches require different alignments of resources and social commitment.



Because the scale of the neuroscientific task is so large, no single individual or lab group can make great progress on their own. It has been increasingly recognised that this also applies to a well-funded large-scale project such as the HBP. Increasingly, a much more open and collective effort has been imagined, where some resources are strategically put in place, but this is used to enhance and build upon the self-organising energy and interest of the community.

An example of this vision is the HBP-funded Collaboratory. The Collaboratory is intended to facilitate collaboration between scientists in the neuroscience and modelling community. Described by our participants as a ‘dating site for scientific collaboration’, the Collaboratory is an online platform that links users to various resources, data, and to one another.²⁹ The platform itself is very simple, a linking service, only as valuable as the tools, data, and relationships available upon it. Some of these tools would initially be provided by projects already underway in the HBP (for example, supercomputing facilities for large scale simulations, a neurorobotics platform, etc.). However, other neuroscience applications available from the greater research community could also be linked so that their services would also be available through the platform. User extensibility is a key driver of such a networking platform. An early goal of the developers is to fix things that users need to make their extensions work. As more users begin to contribute, and more and more users thus find more and more utility from the platform, a virtuous circle is envisioned. More users begets more uses begets more users.

This is very much like the dynamic of the OpenWorm project³⁰, which has pioneered the use of ‘open source culture’ innovations in the organisation of project work. The large community working on the OpenWorm project began through social networking. All of the project meetings happen online, and then are posted online, allowing a large virtual community to participate actively in the project. For many commentators and participants in our workshop, this shows the enormous potential of open source, community based approaches to modelling. Their potential is in building a committed modelling community and drawing in expertise to work in a collaborative way on shared problems, in a way that would be impossible or very difficult for any small group of modellers to do on their own.

As the users of the HBP Collaboratory begin to contribute validation tests for models, tools, and data, this will drive modellers to improve their models. Designers envision that the interaction around models between top-down and bottom-up modellers will eventually draw experimental validation data from the common HBP Neuroinformatics Platform. Ultimately, when users demonstrate that they can use this Platform to generate peer-reviewed publications, the Platform will establish itself as something of continuing value for the neuroscience community.

This strategy of building a platform for sharing—a space for whatever users want to contribute—is primarily a bottom-up strategy. However,, in the view of our participants, it also requires significant resources to establish, and some ‘push from the middle forward’ to be made by the early adopter community.

There are significant challenges in moving from a ‘one of everything but not much of anything’ to ‘a space for many anythings’. While technology is very often a transformative force, ICT projects rarely achieve precisely what they were intended to accomplish. As the workflows of various researchers adapt to these new systems, it will be important to consider what types of dependencies and interdependencies between different parts of researcher communities are created (sometimes accidentally). Where interdependencies are thought of as undesirable (at least in one direction), we might expect resistance or lack of uptake to the new set of social relations brought about by a Collaboratory.

The speed of trust and cooperative competition

Two final remarks can be made before leaving our discussion of building trust, incentive structures, cooperation and infrastructure. First, building trust takes time—it cannot be



built according to a managerial schedule as a deliverable to be achieved on a certain date. The conditions can be provided to encourage trust (such as appropriate protections and balances for all participating parties) but ultimately trust within a community develops slowly, at the speed of individuals deciding that their interests are safe, their participation is valued, and the other party or parties are probably dealing in good faith. Trust can develop initially by providing for voluntary participation when, and as much, and with whom the participant chooses at that time.

Second, unlike the typical contrast between cooperation and competition (which was evident in our fieldwork within the neuroscience community) recent sociological work suggests that there may not be such a simple opposition between cooperation and competition (Sennett, 2012). If cooperation is working together, many forms of competition also require cooperation in order to occur. In a game, participants agree the rules (this is a form of working together) and then compete using the agreed rules (Sennett, 2012, p.5). Competition between labs and between scientists requires a great deal of cooperation (discussion, debate, and ultimately some agreement) about what are the rules, values, and scientific goals with which the competition might be judged. Indeed, science has a strong cultural tradition of very cooperative competition. Building a neuroscience community that can take advantage of future HBP computational infrastructure does not mean dismissing all competitive sentiments in favour of a simplistic image of cooperation. But building this neuroscience community does require practical and material circumstances that might facilitate cooperation (in all its forms, including agreeing fair rules upon which those who strive to improve their scientific reputation might be judged) to be taken into consideration.

At its simplest, from our discussions and our analysis of the key issues involved, we suggest that the basic building blocks of a neuroscience community are fairness (with the skill of being able to understand the needs and social interests of relevant others) and patience (allowing the time for legitimate trust and genuine reciprocity to develop).

4.2.2 Interdisciplinarity for solving new problems

The need for interdisciplinary collaboration in order to understand the brain was recognised at the very beginning of modern neuroscience (Worden *et al.* 1975). Following the example set by the Neuroscience Research Project (NRP), the Human Brain Project brings together a variety of disciplines with differing sets of questions, experimental techniques, traditions of analysis, and expectations of outcome measurement. As with the NRP, in most cases members of different scientific disciplines retain a double disciplinary allegiance—both to their own specific disciplinary community, and to the interdisciplinary nexus in which they are working. Forging this kind of interdisciplinarity around a common project creates unique challenges and opportunities.

Disciplinary and interdisciplinary work

At its most basic level, interdisciplinary work can be defined as work that brings together the methods of two or more disciplinary traditions to solve a difficult problem in a new way. However, the term ‘interdisciplinary’ is often also a catch-all phrase to describe the work of those who are dissatisfied with the constraints or limitations in their present discipline, especially when considering the scope of legitimate research questions and acceptable methods.

“A commitment to a discipline is a way of ensuring that certain disciplinary methods and concepts are used rigorously and that undisciplined and undisciplinary objects, methods and concepts are ruled out. By contrast ideas of interdisciplinarity and transdisciplinarity imply a variety of boundary transgressions, in which the disciplinary and disciplining rules given by existing knowledge corpuses are put aside or superseded” (Barry *et al.*, 2009 pp.20-21).³¹



Within a discipline, those who produce research results within the accepted frameworks can be acknowledged and rewarded through the existing procedures (professional recognition, peer reviewed publications, etc.), enabling them to continue to produce research and progress in their career. An interdisciplinary scholar may have less access to institutionally established means of scientific recognition. Interdisciplinary work takes time to negotiate, extra resource commitments to initiate, and the outputs may be nonstandard, not appropriate for ‘mainstream’ publications, and difficult to evaluate, often coming after seemingly long periods of non-productivity.

The initial challenge is to build bridges between epistemic cultures. The notion of an epistemic culture, introduced by Karen Knorr-Cetina, aimed to capture the processes by which researchers create knowledge: “those sets of practices, arrangements and mechanisms bound together by necessity, affinity and historical coincidence which, in a given area of professional expertise, make up how we know what we know. Epistemic cultures are cultures of creating and warranting knowledge.” (Knorr Cetina, 2007: 361). To bridge between such cultures requires negotiations between often implicit understandings, vocabularies and assumptions. Within this process, specific bridging individuals play an important role in developing interdisciplinary collaborations. However, their potentially precarious role within any particular discipline (and its associated support and scientific recognition structures) may require specific institutional support. Conflicts and misunderstanding are often part of trying to work together across disciplines. Questions regarding what research matters, what counts as evidence, or what knowledge is relevant to pursue, may all be answered differently by those who approach an intellectual puzzle from different disciplinary perspectives. Bridging these different epistemic frameworks is often the first challenge for interdisciplinary work.

Participation in joint meetings, attending conferences together, or reading the literature of one another’s fields may be important first steps to building common ground. Personal exchange is also a valuable aspect of interdisciplinary work, and a way to begin negotiating collaboration. “[Collaborating is] one of the few vehicles whereby you can sit down with a group of people... and just chat and find out what’s going on in the field. For me, that’s more valuable than [research money]” (CBAS 2013). In some cases, proximity of research teams is deemed to be helpful, for example housing research teams in the same building.

Language

An early challenge in negotiating interdisciplinary collaboration is recognising that different disciplines often use the same words with very different meanings. In several instances, participants in our workshop noted that when working with another lab group it took time to reconcile terminology. Thus it is important to begin with clear definitions of terms from each discipline, in order to negotiate and maintain shared meanings across conceptual and cultural divides. In this process, an interlanguage might develop that assists the translation of meaning through different disciplinary perspectives. From our fieldwork with our participants, we could see that terms such as ‘model’, ‘network’, ‘ontology’, ‘biologically realistic’, ‘data driven’, ‘hypothesis-free’, ‘lower scale’, ‘higher scale’ were both crucial to each epistemic culture, yet interpreted differently by participants from different cultures.

Aristotle observes in *Politics* that “though we may use the same words, we cannot say we are speaking of the same things” (cited in Sennett 2012, p.18). In the philosophical tradition, a dialectic conversation proceeds by recognising this difference (through listening skills and debate) and eventually overcoming it with a single meaning. A dialogic conversation, however, can also recognise the difference, but participants are not required to come away with a single answer, only to understand (through listening skills) what the other position is.³² This may be of benefit in the type of exchange between disciplines, sometimes known as multidisciplinary, where participants bring an explanation of cooperative work back into their own field, and the disciplines cooperate



without substantially changing themselves. Most interdisciplinary negotiations find themselves somewhere between a dialectic and dialogic approach. While research results of interdisciplinary work might be translated back into one of the disciplinary languages (and circulate in this manner), communication during the actual interdisciplinary work is predicated upon a sort of interlanguage. Sometimes such an interlanguage lasts only as long as the exchange, but sometimes it may underpin an on-going set of research practices, develop into a subfield, or even establish the foundations for a new discipline.

Individuals who bridge

Bridge scientists, those not aligned to a single world view, are an important asset in building interdisciplinary collaboration and establishing interlanguage—particularly those with the ability to see complementarity and intersection between differing research frameworks. Because it takes a lot of work to keep up in two (or more) different scientific fields, and partial knowledge or lack of specialisation may be equated with poor scientific evaluation, the bridge scientist potentially faces challenges in having the value of their work recognised. In some cases, specific support directed towards interdisciplinary scholars will benefit interdisciplinary projects—this is particularly true for early career scholars who already face numerous challenges in establishing themselves through interdisciplinary work.

Conflict, trust and time: challenges in assessing interdisciplinary work

Conflict, competition and misunderstanding are a normal part of building an interdisciplinary process. Our fieldwork shows clearly that it is important for difficult issues, such as conflict in world view, to be addressed rather than avoided. Trust is an important part of interdisciplinary collaboration, which takes time and careful interaction to build. Many of the factors encouraging trust within a community have been discussed above. Physical proximity can help build trust in interdisciplinary collaborations. It certainly allows for greater interaction, negotiation and is part of the architectural logic of some new purpose-built interdisciplinary centres (CBAS 2013).

Because negotiation across epistemic boundaries takes time, because developing the knowledge of another field takes time, and because constructing shared terminology must be negotiated, interdisciplinary research often takes a far greater length of time to produce outputs. These outputs may be in a nonstandard form and therefore difficult to evaluate. The challenge from the outside (for example from the perspective of science policy professionals) is that interdisciplinary projects often require prolonged support without immediate results and (when results are achieved) are difficult to assess.

The larger context and rationales of interdisciplinarity

Emphasis on interdisciplinarity within the Human Brain Project is part of a larger discourse within science and particularly within science policy throughout Organisation for Economic Cooperation and Development (OECD) countries. A number of rationales justify interdisciplinarity in contemporary science discourse. Accountability is certainly one of these. By this rationale, if science is to be accountable to publics (and civil servant representatives of publics) it must respond to the research questions that publics will benefit from and open up new areas of research that older disciplinary forms of scholarship might not deem valuable within their own epistemological lens.³³ Nowotny *et al.* argue that a new mode science, which replaces the previous organisation of science, is taking effect (Gibbons *et al.* 1994, Nowotny, Scott, & Gibbons 2001). This ‘mode-2’ science is characterised by the growth of transdisciplinary research, novel forms of quality control (which undermine established disciplinary forms of evaluation), a displacement of a culture of autonomy of science with an emphasis on accountability, research importance attached to the ‘context of application’, and a diversity of locations and types of locations at which knowledge is produced (Barry *et al.* 2009 p.21).



Interdisciplinarity is also linked to the rationale of innovation. By this logic, innovation can be improved by breaking previous boundaries to combine research at new sites of interest and create new objects for study. In a ‘knowledge economy’ where new forms of knowledge production are potentially treated as economically valuable, this has also linked innovation rationales for interdisciplinarity to economic logic: economic benefit (regardless of how it is societally distributed) can be said to be in the public interest, and thus the logic of accountability and the logic of innovation are sometimes intertwined in discussions of interdisciplinarity.

The contemporary emphasis on interdisciplinarity cannot, however, be reduced to the logics of accountability and innovation in themselves. Interdisciplinarity does not always mean the reduction of scientific autonomy; in fact, it often leads to new forms. For example, this can be seen in the formation of new disciplines, as the contemporary disciplinary autonomy of ‘the neurosciences’ (formed from a mixture of cross disciplinary collaborations) demonstrates (see subsection below: *Then and now*). Nor can interdisciplinarity be said to always improve innovation. Barry *et al.* (2009), concluding a large study on interdisciplinarity, locate, intertwined with the other rationales, an argument for or emphasis on ontological transition—the demand that new types of questions be asked and new types of objects be explored. The slightly agonistic attitude of scholars seeking to break free of traditional disciplinary boundaries is a remark on what kind of things and relationships can exist in the world (ontology³⁴), and hence what type of questions are legitimate to ask.

Then and now: historical examples of interdisciplinary relations

It is tempting to think that science in the past was done in a disciplinary manner and that those disciplines were expressive of natural boundaries, perhaps even matching the way that nature itself was organised. However, this has never been the case. The history of science shows that disciplines have always been formed by social and institutional forces that have led to the grouping of intellectual practices. Disciplines have formed and unformed as the objects of scientific research have changed and as the social and economic factors that organise science have shifted.

The initial HBP proposal was developed in response to the EU flagship science call. This was funded from the EU computer science and research infrastructure budget for scientific programmes with a significant computing component. Computer science is expected to be involved in HBP neuroscience in two ways. New computational infrastructure and new techniques are required to successfully analyse the vast amount and unusual complexity of neuroscientific data. At the same time, the insights of neuroscientific discoveries are expected to contribute to more efficient and effective computing, with new powers that can be deployed in novel ways within the economy. There is a great deal of interest in computing, robotics, algorithm determination, and pattern recognition abilities that are expected to be side effect knowledge of Future Neuroscience research, and of direct benefit to future computing and future robotics. These potential synergies and their ethical and societal import are the topics of our third (forthcoming) foresight report (available after March 2016).³⁵ Within this report, *Future Neuroscience*, it is relevant to note that computational neuroscientists are a minority fraction (perhaps 10%³⁶) of the overall neuroscience community. At least some of the aforementioned conflict around the HBP (see Section 3.1) can be attributed to tensions arising across subfields within a broader discipline when resources are seen to be being reallocated (or in this case allocated³⁷).

Accountability debates and open source models

One of the challenges for scientific communities is to navigate grassroots interdisciplinary collaborations within or alongside the institutionally engineered interdisciplinarity that often accompanies resource allocation from external funders.



This is one of the key challenges for the HBP strategy. The ‘Collaboratory’ (discussed above Section 3.2.1) borrows from ‘open source culture’ in the computing world to envision an enthusiastic volunteer driven community. A debate that occurred between some of our informants during our Foundation Brocher workshop concerned the viability of modelling a publicly funded European Flagship Science project on a volunteer driven example (such as OpenWorm, the most successful open source brain modelling initiative to date). To paraphrase some comments: ‘what if someday they don’t feel like getting up in the morning? Shouldn’t there be a plan for integrating strategies?’ Platform designers were quick to acknowledge the need for “some level of high level coordination to organise some things,” but also to underline the fact that the open source model really did produce real technology.³⁸ The openness of an Open source community was about providing the information necessary for anyone to participate. There is never a requirement that participants are volunteers. Staff members paid to contribute to the project would begin before such a voluntary community existed, and would continue with or without it.

Managers may well believe that creating a vibrant open source community is supplementary to the project from a managerial standpoint, and designers of the Platform are under no illusion that such a community can be created around every project. However, this may miss a very important point. While such a community in itself may be a useful but not necessary supplement, the quality of trust and community involvement in the project is not supplemental to the success of the project overall. And one of the culturally expected ways to build community, establish trust, (perhaps the most expected way) within coder communities (of which modellers participate) is to use open source project management practices.³⁹ So in this sense, such a strategy is not at all supplemental to building and strengthening a cooperative neuroscience research community.

4.2.3 Social and ethical issues: researcher (self) awareness and societal impact

This report does not address the long-term societal impacts of Future Neuroscience, in part because much of the debate on potential positive and negative outcomes is speculative. In our fieldwork, individual neuroscientists commonly expressed that the long-term outcomes of new neurotechnologies were not relevant to their day-to-day research work. While they hoped that society took up the potential benefits of research and innovation in positive ways, this was not something, according to them, that was in their hands—indeed they were of the view that it was almost impossible to know or control possible uses that would emerge from the basic science. The same new insight into neuroscience principles that might be used clinically to build a brand new (neuromorphically synchronised) artificial limb for an amputee might also be used militarily to control a search and destroy drone, or commercially to extend robotic activity into new places in the labour market.⁴⁰ In this report, rather than dwelling on the future, which is difficult to predict, and speculating the long-term impacts of HBP research, we have focused on the ethical issues of fairness within the research system. We have drawn researchers’ attention to the importance of having an awareness of their position and role within the social arrangements of neuroscientific community, both in terms of how that impacts the outcome and quality of scientific results, and how that impacts fairness. One of the vital skills to make a successful transition to a culture of data trust, data sharing and interdisciplinarity, which we have identified here as important to the success of the HBP, is researcher self-awareness. This skill of ‘reflexivity’ is not only crucial for the local goals of building Future Neuroscience computing infrastructure; it is also, when put to the service of fairness in the social arrangements of the scientific community, the basis of thinking about the ethics of responsible research. In the long-term, it is the basis for building a culture of Responsible Research and Innovation (RRI).

In the short term, grappling with issues of fairness in scientific cooperation, and the overall objectives of the HBP, we hope that the HBP will help create a community that is



not only collaborative but also committed to considering the social and ethical issues raised by the outcomes of their research. In the medium term, the experimental neuroscience research must be in dialogue with other professional communities to whom it might contribute. For example, there is already a need for more interdisciplinary relationships with clinical neuroscience among other professional and stakeholder communities. Collaboration with stakeholder groups who may have an interest in the outcomes of HBP research should start now. In the long-term, the neuroscience community must continue to think through its obligations of accountability to the public in all its diverse manifestations.⁴¹ The skills for considering issues of fairness in scientific cooperation (in which all parties consider the needs and interests of other parties, as well as the overall objectives of the project) can thus also provide at least some of the bases for thinking about fairness in wider society.



5. Conclusions and Recommendations

- A technological infrastructure, in this case a research (and innovation) infrastructure, reflects and embodies a certain social organisation involving power relations. Hence, for some issues, technological fixes cannot replace social solutions. Building an infrastructure to support Future Neuroscience must go hand in hand with supporting a community that can make use of this infrastructure, and also wants to do so. It is therefore necessary to consider how design decisions will potentially affect the social organisation of the future research community, and to consult with and include potential users in the design process
- A new ecology is emerging in neuroscience, with a focus on scaled-up industrial speed research groups, linked to differentiated artisanal smaller scale research groups focused on specific experimental skills that large-scale labs find difficult to reproduce. In this ecology, more attention needs to be paid to the human dimension of the research infrastructures, at several levels.
- At the individual level, incentives, and success metrics for new academic profiles (curators; ‘bridge scientists’) must be found for rewarding the sharing of data, the collaboration to pre-competitive model development and acknowledging the work involved for the data producers and the data curators.
- At the interpersonal level, there is a strong need for trust and mutual understanding, and, perhaps, a lightening of the burden of continual scrutiny and evaluation of success, to allow more flexibility and accept the possibility of failure.
- A flexible strategy should be developed and implemented for improved and coordinated communication between the various individuals and entities, while preserving spaces ‘private’ to the project. This requires, in the short term, a dedicated budget for organising internal events separate from public events.
- New approaches need to be adopted to link the work of the Medical Informatics Platform more firmly and openly into existing networks, organisations and patient groups, and to develop additional approaches for bridging between the HBP and clinical communities.
- There is a need for supporting dedicated curators of data and metadata within the Neuroinformatics Platform, who have the appropriate interdisciplinary background to address the challenge of scaling up small data and that of bridging scales, and also to identify possible complementarities and act as broker between research groups.
- The integrative design of the Human Brain Project infrastructure must take care not to over-privilege certain characteristics of the brain to the detriment of some important aspects, like plasticity and neuromodulation.
- Interdisciplinary collaboration is very much part of this process, and suitable time and resources should be allocated for establishing interdisciplinary work.
- A participatory research community needs to encourage individual researchers to understand their role within the community. There is a need for a programme for researcher awareness. This begins by supporting researchers’ knowledge of their own role and impact within their immediate research community, and includes researcher interaction with other potential user communities, especially clinical neuroscience and patient communities.

6. Further Reading

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7. Endnotes

¹The report is available here: <http://www.kcl.ac.uk/sspp/departments/sshm/research/Research-Groups/Biomedicine-Ethics-and-Social-Justice/BESJ-Projects/HBP/Report-on-future-medicineWebsite-version.pdf> , consulted 11.09.2015

² https://www.humanbrainproject.eu/en_GB/project-objectives, consulted 24.8.15

³ The following description is drawn from the Framework Programme Agreement that the HBP agreed among its members and with the European Commission over some months of discussion in 2015.

⁴ The report is available here: <http://www.kcl.ac.uk/sspp/departments/sshm/research/Research-Groups/Biomedicine-Ethics-and-Social-Justice/BESJ-Projects/HBP/Report-on-future-medicineWebsite-version.pdf>

⁵ DBT website. *Dual use and neuroscience. An online debate on current developments:* <http://www.tekno.dk/article/dual-use-and-neuroscience-invitation-to-an-online-debate/?lang=en> , consulted 04/09/2015

⁶ DBT website. <http://www.tekno.dk/article/opening-up-the-human-brain-project-to-the-neuroscience-community/?lang=en> consulted 04/09/2015

⁷ More information available here: <http://www.kcl.ac.uk/sspp/departments/sshm/newsrecords/Foresight-Lab-Workshop-at-Brocher.aspx>

⁸ Report of the Workshop available here: <http://www.kcl.ac.uk/sspp/departments/sshm/research/Research-Groups/Biomedicine-Ethics-and-Social-Justice/BESJ-Projects/HBP/Report-Workshop-Fondation-Brocher-2015---Final.pdf>

⁹ 1st Technical Review Human Brain Project (HBP): Main conclusions & recommendations, consulted 07/08/2015: <http://ec.europa.eu/digital-agenda/en/news/1st-technical-review-human-brain-project-hbp-main-conclusions-recommendations>;

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The Human Brain Project Adapts and Moves Forward After a Constructive Mediation Process, consulted 07/08/2015: https://www.humanbrainproject.eu/en_GB/-/the-human-brain-project-adapts-and-moves-forward-after-a-constructive-mediation-proce-1;

Call for Expressions of Interest on Systems and Cognitive Neuroscience, consulted 07/08/2015: https://www.humanbrainproject.eu/en_GB/call-eoi.

¹⁰ In contrast to ‘small data’, ‘big data’ “are characterised by being generated continuously, seeking to be exhaustive and fine-grained in scope, and flexible and scalable in their production.” (Kitchin, 2014: 27).

¹¹ <http://www.openconnectomeproject.org/>, consulted 03/09/2015; <http://neuromorpho.org/neuroMorpho/index.jsp>, consulted 03/09/2015.

¹² <https://www.whitehouse.gov/BRAIN>, consulted 03/09/2015; <http://alleninstitute.org/>, consulted 03/09/2015.



¹³ CLARITY is a method for making brain tissue transparent. It transforms chemically intact biological tissue into a hydrogel-tissue hybrid, making it amenable to brain imaging techniques with unparalleled detailed results (Chung *et al.*, 2013; Tomer *et al.*, 2014).

¹⁴ In the biomedical domain, the term ‘ontology’ covers a wide diversity of artifacts. In the strict sense inherited from computer science, an ontology is a formal representation of a knowledge domain “with definitions of concepts, their attributes and relations between them expressed in terms of axioms in some well-defined logic.” Yet the most common ontological artifacts are terminologies, or controlled vocabularies, and to a lesser extent, data models (Brazma *et al.*, 2006; Rubin *et al.*, 2007).

¹⁵ <http://www.jfsowa.com/computer/standard.htm>, consulted 14/08/2015.

¹⁶ <http://socialsciences.exeter.ac.uk/sociology/staff/leonelli/>, consulted 03/09/2015.

¹⁷ The Neuromorphic Computing Platform of the Human Brain Project will allow non-expert neuroscientists and engineers to perform experiments with configurable Neuromorphic Computing Systems (NCS) implementing simplified versions of brain models.

¹⁸ <https://github.com/>, consulted 03/09/2015.

¹⁹ <http://opensourcebrain.org/>, consulted 03/09/2015.

²⁰ <http://neuralensemble.org/meetings/HippocampCA1/>, consulted 13/08/2015.

²¹ <http://neuralensemble.org/meetings/HippocampCA1/>, consulted 13/08/2015.

²² This particular issue was forcefully flagged during the Expert Seminar entitled “Theory and data for advancing Future Neuroscience and the Human Brain Project”, organised jointly by the Danish Board of Technology Foundation (in SP12), the European Institute for Theoretical Neuroscience (in SP4), the High Performance Computing Group Subproject (in SP7) and the Researcher Awareness Group (in SP12), which took place in Paris, 21-22 May 2015.

²³ APIs (Application Program Interfaces) are sets of routines, protocols and tools for building software applications. Monitoring APIs are typically used to track performance, usage and users of an ICT platform.

²⁴ <http://www.epicureproject.eu/home.aspx>

²⁵ One informant from our fieldwork said people would “rather share their toothbrushes than their data.”

²⁶ This concern has been discussed earlier. For the given responses to other listed concerns see Koslow (2000).

²⁷ At the more dystopian end of future scenarios, one outcome of the failure to grapple with validity issues might be that computer modelling comes to be seen as a secondary discipline with less status providing a service for biologist neuroscience. Lewis and Bartlett (2013) document evidence of this situation for other bioinformaticists in post-genomic science. Whereas biologists produce *primary inscriptions* (original experimental data) the bioinformaticists are often institutionally dependent, or subordinate, in the task of producing *secondary inscriptions* (processing data). Their case study was taken from molecular biology.

²⁸ For a more specific discussion of how provenance is being discussed within the HBP see Section 2.2.1 above.

²⁹ Users would be able to log-on to a common web interface with an HBP identity and access multiple application programs. A provenance service would support technical data distribution and code attribution. In addition to applications the web interface would support various source-controlled python script with explicit package dependencies (known as Tasks). An overall software foundation (of necessary packages to run analysis applications) would be brought together through the Collaboratory, some developed or enhanced by the HBP and more coming from 3rd party sources as the user community extends the functionality of the Collaboratory



³⁰ Initiated by Stephen Larson, a participant in our workshop at Fondation Brocher.

³¹ Terms like multidisciplinary/interdisciplinary/transdisciplinary are sometimes distinguished. “Commonly, a distinction is made between multidisciplinary - in which several disciplines cooperate but remain unchanged, working with standard disciplinary framings - and interdisciplinary - in which there is an attempt to integrate or synthesize perspectives from several disciplines.... Transdisciplinarity, in contrast, is taken to involve a transgression against or transcendence of disciplinary norms...” (Barry *et al.* 2009 pp.27-28). For the purposes of this report we have this report we use the word ‘interdisciplinary’ as a general indicator of a continuum of meaning from multi- to trans-.

³² For this argument see Sennett 2012 pp.18-20. The term dialogic is taken from the literary critic Mikhail Bakhtin.

³³ Participants in our workshop frequently grounded arguments about research direction in the expectation that publicly funded research would ultimately be of some benefit to the public. Clinically relevant neuroscience findings were seen as one important goal.

³⁴ We place this (sociological) definition of ‘ontology’ in juxtaposition with the aforementioned biology and computer science definitions of ‘ontology’ (see footnote 12 above) as an example of the interdisciplinary practice of defining terms and sharing these definitions.

³⁵ For this report it is enough to note that this two way framing of the HBP within the logics of accountability and innovation is part of the overarching framework of interdisciplinary match making (by EC science policy) between neuroscience and computer science.

³⁶ This figure was given by one of our research participants to frame the potential for a clash of sensibilities between communities within the neurosciences.

³⁷ Strictly speaking financial resources were being allocated. The FLAG-ERA grant was new money coming into the neuroscience community. From certain perspectives, community identity and the balance of reputational resources were seen to be being reallocated. In-community political resource (the power to influence the direction of one’s community) was also seen to be being shifted.

³⁸ The notable example was the Android operating system (based on the open sourced Linux kernel) in the mobile phones in the pockets of many of the participants in the discussion on that day.

³⁹ One elision here is variation within the culture of neuroscience, some of which very much overlaps, both in form of task and values, with coder communities (for whom open source models are seen, by and large, as desirable), and some of which has a more traditional culture of hierarchical science within a role differentiated laboratory. While this distinction which we point to, may be a challenge for an open source trust building data sharing strategy, it is no less so for any other type of trust building data sharing strategy that the HBP might select.

⁴⁰ So for some it was time to forget the social and ethical issues, get back to basic research and let the technologists worry about social impact. We note that the social sciences community has clearly made the case that responsible innovation (RI) begins with responsible research (Sarewitz & Guston 200x, Fischer 200x, Wynne 200x). The research lab is one of the first places where new possibilities are discovered and thus one of the first places that responsible assessments can be made. The ability in the long term to do societal assessment of potential new innovation directions is developed from the short-term researcher awareness of their own role and impact within their immediate research community.

⁴¹ In our Future medicine report we gave examples of respecting neural diversity by building more links with the disability community; and engaging early with clinician and patient communities among others.